ID6003 – AI in Process and Logistic optimization
Assignment Report

Assignment:
Controller Design and Analysis

SOUMYA MUKHERJEE
CH24M571

1.0 System Identification and details

(a) I have chosen the Production–Inventory Level Control System as the first order system .

The inventory level is regulated by manipulating the production rate so that it can match demand and maintain a desired inventory set-point .

Transfer Function:

For a basic first-order inventory control system, the transfer function relating inventory output **I(s)** to the production release order PREL(s) (input) is typically:

$G(s) = K / Ts+1$

Where G(s) is the transfer function of the inventory process , K is the static system gain and T is the time constant (lead time) representing the production and delivery delay .

Input variable u(t) :
Production rate (units/ hr) - Manipulated Variable (MV)

Output Variable y(t):
Inventory level (units) - Process Variable (PV)

Setpoint r(t) :
Desired Inventory level - Control Variable (SP)

Control Output OP(t) :
Controller signal to production unit - Output Variable (OP)

Disturbance d(t) :
Customer demand rate - DIsturbance Variable (DV)

(b) **Simulation of the Open-Loop System**

The open-loop response of the system (without feedback control) was simulated for a step increase in production rate. The output (inventory level) increases gradually and asymptotically approaches a steady-state value determined by the gain K.

For simulation parameters:

$K=1, T=10$

The open-loop step response is denoted as :

$y(t)=K(1-e \wedge (-t/\tau))$

Observation:

The system is stable and exhibits exponential rise behavior. However, without feedback, any change in demand (disturbance) or setpoint leads to significant steady-state errors.

c) **Controller Design**

A Proportional–Integral (PI) Controller was selected:

$C(s) = Kp + Ki/s$

This controller automatically adjusts the production rate to minimize steady-state inventory deviation and respond to demand changes.

For the above chosen controller :

1. The proportional term ensures a fast corrective action proportional to inventory deviation.

2. The integral term eliminates steady-state error (ensuring long-term inventory balance).

3. A derivative term (in PID) was avoided to reduce sensitivity to measurement noise in inventory sensors.

d) For controller tuning , 2 scenarios were considered

1. Kp=0.8, Ki = 0.1 -> Smooth, stable response with acceptable rise time
2. Kp =1.5, Ki = 0.25 -> Faster response but higher variability and mild overshoot

Analysis on chosen model : 1 lag Auto regressive with exogenous input

The ARX model-based analysis effectively identified the dynamic characteristics and variability of the control loop.
It provided quantitative insights into how controller tuning parameters influence:

- Responsiveness (via estimated poles)
- Stability (via residual correlation)
- Variability (via variance ratio metrics)

Such data-driven performance evaluation is valuable in logistics applications, where physical modeling is often uncertain due to variable demand and lead times.

Summary of the results :

Scenario A:
better tracking per IAE (369.86 vs 533.53) and ISE (597.04 vs 821.20), but shows **higher PV variability** (PV_std 1.827 vs 1.546) and higher OP_std (0.198 vs 0.134).

Scenario B:
Slightly **higher service_level** and **lower stockout metrics** but worse tracking error (higher IAE/ISE).

Scenario A yields **tighter tracking** (lower IAE/ISE) but larger variability in PV and OP — more aggressive corrections from controller integral action produce variance but reduce integrated error.

Scenario B produces **smoother OP** (lower OP_std) and lower PV variability but at the cost of larger tracking error (higher IAE/ISE). If the assignment required "high PV variability with no sustained oscillation".

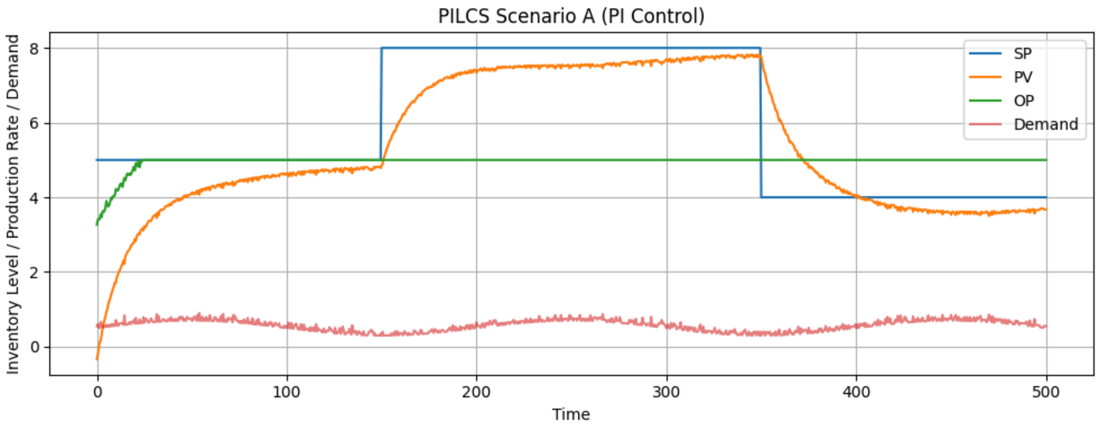
Based on the two scenarios chosen , the following conclusion guides the choice .

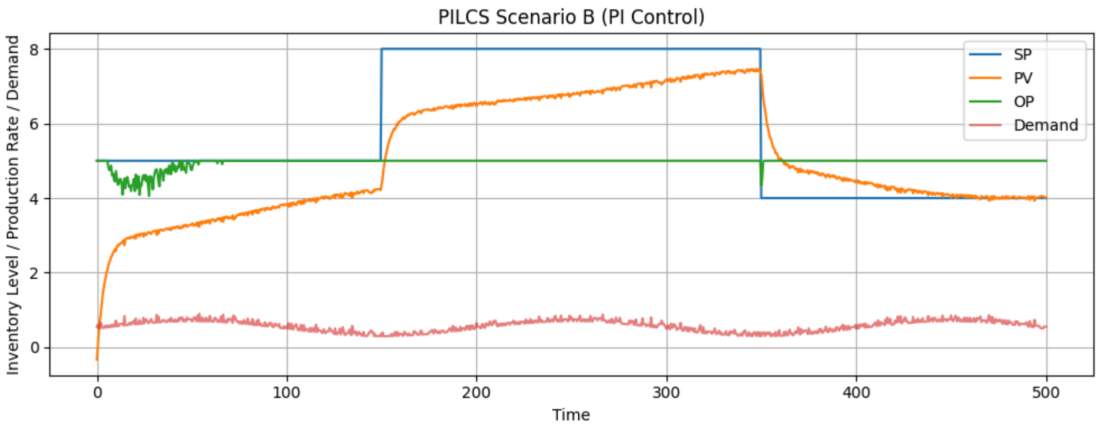
Kp up increases responsiveness, Ki speeds offset removal but can amplify variability/oscillation . This can help us tune to balance IAE vs PV_std.

For the Scenario A we have better tracking but more variability and slightly higher stockout risk but with Scenario B we have smoother, safer inventory with worse integrated tracking.

—---

Plot analysis





From the above 2 plots it is evident that Scenario A is more aggressive — better tracking (lower IAE/ISE) but higher PV/OP variability and slightly higher stockout risk. Scenario B is more conservative — smoother PV and OP with higher service level and fewer stockouts, at the cost of larger integrated tracking error. We should choose A when **minimizing integrated error is primary**; and should choose B when **operational smoothness and safety** are primary.